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DURIP 1999 Final Report

Contract # F49620-99-1-0221
(April 1, 1999 to September 30, 2001)

"MOCVD Growth with in-situ characterization and femto-second two-color laser experiments
for widegap III nitride materials and device development."

December 10, 2001

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Summary

This award provided funding for instrumentation that enhanced Oklahoma State University's research capabilities and strengthened our existing DoD-sponsored programs in the areas of semiconductor materials and device research, especially for MOCVD, MBE growth and characterizations for photonic applications. The instrumentation is applicable to a variety of semiconductors; however, our initial focus was on wide gap semiconductors, particularly group III-nitrides, GaN, AlN, InN and their alloys and heterostructures. The instrumentation is the Reflectance Difference Spectroscopy (RDS) system and separately tunable two-color Dual Frequency Femtosecond Laser Spectroscopy (DFLS) system. These systems interfaced to existing equipment procured with DoD funding, including a Thomas Swan MOCVD nitride growth reactor and a picosecond resolution streak camera.

The RDS system is portable and will be initially attached to our new MOCVD growth reactors for in-situ III-nitride growth monitoring and growth condition optimizations. A variety of AlGaN and InGaN based multi-layer device structures were grown for high temperature/power electronics and UV-blue photonic device applications such as AlGaN UV photodetectors and UV laser diodes. Lateral epitaxial overgrowth (LEO) approach used on various substrates including Si, sapphire and Eagle-Picher ZnO. An array of microstructures will be grown by selective area overgrowth and processed for high power emitter and display applications. Additionally, specially designed AlGaN and InGaN multi quantum wells were grown to study fundamental electrical, optical, and structural material properties. The RDS system was also used for real-time semiconductor MOCVD surface studies and chemical reactions occurring with MOCVD precursors. Post-growth semiconductor characterizations are also planned with RDS. The DFLS system is based on all solid-state, nearly maintenance free lasers. The newly introduced 10W (largest capacity commercially available) diode laser pumped Nd:YAG laser (Millenia X) is very compact and portable, operating with a standard 110V wall plug-in. This Millenia X Nd:YAG laser pumps two Ti:Sapphire lasers, which are phase locked to each other to generate two separately tunable coherent femtosecond pulses. This state of the art DFLS system can be used for a variety of spectroscopic applications. Initial emphasis was on III-nitride research such as pump-probe time- and frequency-domain experiments for stimulated emission and lasing studies in AlGaN and InGaN-based structures. The DFLS system was also used for coherent transients and nonlinear optical studies of semiconductors pertinent to device applications such as switches, modulators and THz beam generators, as well as for elucidating fundamental processes occurring under high carrier density excitations. Because they are portable, femtosecond lasers can also be used for MOCVD and MBE in-situ growth studies.

Acquired Equipment

Acquisition Date	Manufacturer	Description	
11/11/1999	Rhea Corporation	Detector, CCD System	\$5,110.00
11/11/1999	Ocean Optics Products for Research	Spectrophotometer	\$3,003.00
2/21/2000	Hamamatsu Corp.	Heat Exchanger	\$4,120.90
3/27/2000	Melles Griot	Photomultiplier Tube	\$2,445.70
3/28/2000	SPEX Industries	Laser, Helium, Cadmium	\$9,268.40
3/28/2000	SPEX Industries	Module, High Voltage Power Supply	\$785.86
3/28/2000	SPEX Industries	Photon Counting Acquisition System	\$2,910.85
3/28/2000	SPEX Industries	Module, High Voltage Power Supply	\$785.86
7/20/2000	Technical Mfg Group	Table, Laboratory	\$2,490.00
9/1/2000	Thomas Swan	Susceptor, SIC Coated	\$1,600.00
12/7/2000	Laser Resale	Cabinets, Gas Used W/ZECL Accomodating	\$2,500.00
4/11/2001	Aixtron	MOCVD #2 (partially paid here)	\$132,532.25
		Other supporting materials for equipment	\$2,140.91
		Freight charges for shipping equipment	\$306.27
		Total	<u>\$170,000.00</u>

AFOSR-DURIP Report

Contract: #F49620-99-1-0221

**"MOCVD Growth with In-Situ Characterization and Femtosecond
Two-color Laser Experiments for Widegap III-Nitride Materials
and Device Development"**

March 31, 1999-June 30, 2001

1. MOCVD growth improvement

A custom made in-situ growth monitoring system was installed in a Thomas Swan GaN MOCVD system (GaN Epitor) and utilized for InGaN related material and device growth. Both IR interferometer system and blue reflection system have been applied for optimization of various growth parameters, which results in successful development blue LED structures.

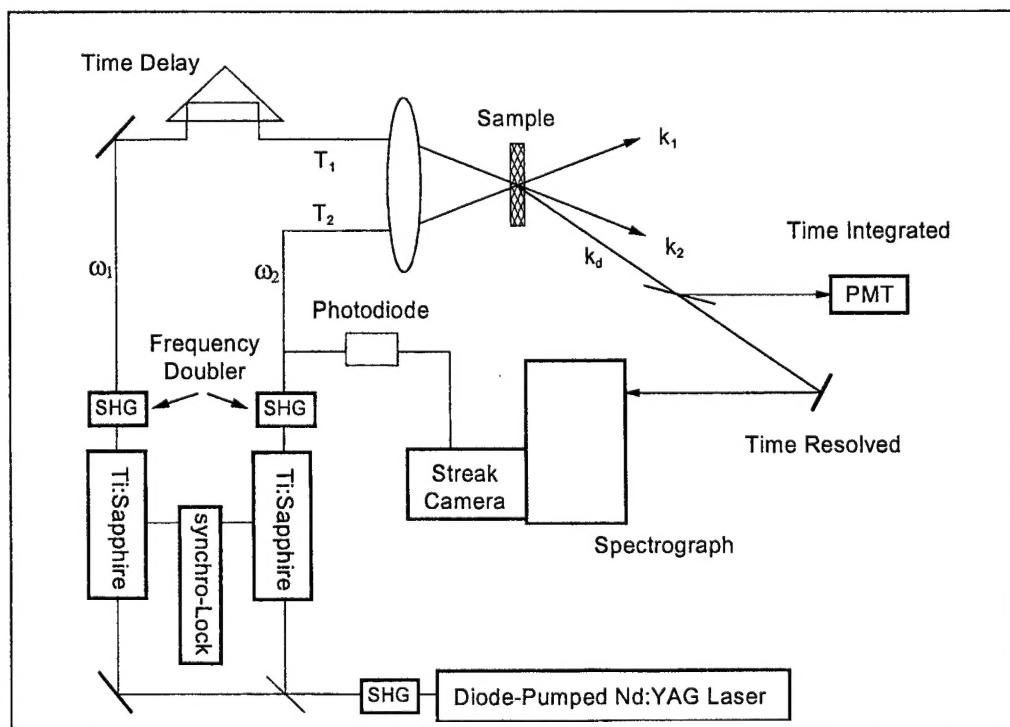
A new AIXTRON MOCVD system (HT200 RF-S) dedicated for the AlGaN was purchased and installed. A commercially available in-situ monitoring and analysis equipment have been purchases with this MOCVD system, and will be utilized for the research on high Al composition AlGaN growth and analysis of the growth mechanism.

We believe that commercial nitride MOCVD reactors are not as well-functioning as those for other materials such as GaAs, and that the MOCVD nitride reactor should continue to be modified as we go along.

Most importantly, it is widely believed that the defects in GaN related material dominantly affect the overall quality of GaN related materials and devices. Understanding of the growth mechanism and precise control of the growth parameters by the various in-situ monitoring and analysis system becomes more critical to the quality control and the development of the final devices.

2. Femtosecond laser system

We upgraded the dual frequency femtosecond lasers. The outline of the system is depicted below.



We modified and optimized our femtosecond laser-induced high carrier density setup for pump-probe experiment, as well as harmonic generation experiment over a wide wavelength range. With our femtosecond laser, we performed important experiments which result in many publications. The complicated theoretical interpretation of our experimental results was made by the Professor Y. C. Chang at the University of Illinois.

In addition, a visiting scientist from Russia collaborated in the use of our femtosecond laser system for harmonic generation in III-nitride materials and their heterostructures, a research area nearly unexplored yet. The results are now on interpretation and theoretical analysis.

Additional technical details can be found in the following documents.

A. Publication List.

B. Two articles from the Journal of Crystal Growth:

- 1) MOCVD growth, stimulated emission and time resolved PL studies of InGaN/(In)GaN MQWs: well and barrier thickness dependence.
- 2) Growth and in situ monitoring of GaN using IR interference effects.

C. A Ph.D. thesis in the Department of Physics: “” by Chan-Kyung Choi.

RECENT PUBLICATIONS AND ABSTRACTS (1999-JUNE 2001)

Publications (refereed):

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